Combination of Body Sensor Networks and On-Body Signal Processing Algorithms: the practical case of MyHeart project

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Abstract

Smart clothes increase the efficiency of long-term non-invasive monitoring systems by facilitating the placement of sensors and increasing the number of measurement locations. Since the sensors are either garment-integrated or embedded in an unobtrusive way in the garment, the impact on the subject's comfort is minimized. However, the main challenge of smart clothing lies in the enhancement of signal quality and the management of the huge data volume resulting from the variable contact with the skin, movement artifacts, non-accurate location of sensors and the large number of acquired signals. This paper exposes the strategies and solutions adopted in the European IST project MyHeart to address these problems, from the definition of the body sensor network to the description of two embedded signal processing techniques performing on-body ECG enhancement and motion activity classification.

1. Introduction

Monitoring systems sensing human physiological signals relying on wearable sensing are currently being developed by many organizations. Wearable systems have several advantages compared to standard monitoring approaches: these include better sensor placement and an increased number of sensors without compromising garment comfort. The increase in the number of sensors is due to the possibility of integrating sensors directly in the garment fabrics ("functional yarns"), sandwiching microcircuits between fabric layers and collecting signals using small electronic devices with conveniently unobtrusive form factors (see, for example, [9], [11]). The automated monitoring of physiological parameters without the presence of caregivers suffers from signal quality fluctuations due, for instance, to changes in skin contact of textile electrodes and electrical or movement artefacts. The acquired signals must further be made available both to the user, for information purposes, and to professionals, to provide feedback or assistance when needed. Signal quality must therefore be enhanced for readability and the amount of data reduced.

Figure 1. MyHeart instrumented shirt - skin layer; Textile electrodes are clearly visible on this under layer of the garment

The collection of more data from the larger number of sensors forces development of on-body processing of information, aiming to reduce the total amount of data to be transmitted to the outside world (by means of a mobile 'phone). Embedded signal processing techniques are therefore used to extract the relevant features from the biosignals on real time.

On-body sensor networks, wireless communication with external devices (mobile 'phone, patient station) and embedded signal processing are addressed in this paper.

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2. Body sensor network

One of the main advantages of body sensor networks on sensorized garments is that sensor modules can be supplied with power from a single centralized source, avoiding the presence of several distributed batteries. Moreover, on-body communication can be performed over a "wired" network. The sensor nodes can therefore be reduced in size, since they require neither a local battery [6] nor an additional wireless communication module.

2.1 Network architecture

Two main network architectures have been considered for the MyHeart project. The sensors could either be directly connected to wearable electronics using dedicated tiny conductive wires knitted like normal textile yarns, or local processing nodes could be designed to acquire the signals from different sensors. In the latter case, local area network technologies such as field-bus [10] [5] can be used to carry enhanced and preprocessed signals to a central wearable unit. The first scheme was used in the first phase of the MyHeart project, while the second one with de-localized collecting and pre-processing nodes will be used in subsequent project phases. Figure 2 shows the on-body electronics developed by CSEM.

Figure 2. First prototype of SEW (Wearable Side Electronics): the CSEM's on-body electronics module

In this paper, discussion will be restricted to the case using the wired serial bus since it reduces the number of wires between nodes, consequently decreasing the susceptibility to external electromagnetic noise. Compared to conventional point to point links, network-based solutions exhibit several further interesting advantages [3]: it is possible to transport control information in addition to the physiological data, cabling costs are reduced since the number of wires and the connector size are both reduced, acquisition and processing may be easily separated, extensions may be performed much more quickly and at lower cost because little or no cabling is necessary, and values from a sensor or any application may be transmitted to any other node avoiding duplicating sensors and cables.

The lower data-transfer resulting from the sharing of the medium (compared to dedicated wires for each sensor) is not a limiting factor in the case of MyHeart project, since the acquired physiological signals require only small channel bandwidths.

2.2 Sensor modules: size and synchronization aspects

Experience with the current shirts and accelerometer modules shows that if a sensor module is small enough it will not be noticed by the user. Sensor modules must therefore use small component packaging, be optimized to avoid using a crystal or a ceramic resonators and still provide sufficient endurance to electrostatic discharges which could occur during use of the shirt.

The communication bus is controlled by the device which provides the interface between the shirt and the outside world. As the number of connection lines consists only of the power supply and a single data transmission, the connector between the shirt and the device becomes very small. The device will manage the power supply and provides a means to synchronize the acquisition and the clock of the sensor modules, by sending a known synchronization pattern which can be used by the modules to calibrate their internal clock.

2.3 Data flow requirements

The data transmitted across the body sensor network will be received in the on-body electronics by the signal processing modules. Because of its physiological nature, data flow integrity must be ensured throughout the network. The MyHeart project complies with the following requirements: [7]: periodic traffic with different period durations as well as sporadic traffic with bounded latency are handled, a mechanism to know the order in which events have occurred for sporadic traffic is provided, quasi-simultaneous sampling of a number of inputs is allowed and both point-to-point and broadcasting mechanisms are contemplated.

2.4 Communication to the outside world

A communication channel is established between the on-body electronics (which centralize and process the data from different nodes) and a mobile 'phone. The communication is performed using Bluetooth, since this technology is widely available on current GSM phones: a Java program has been designed in the MyHeart project to interact with the user. The cellular 'phone is furthermore used to forward the acquired and processed signals to a monitoring

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centre, allowing professional care-givers to consult the patient's data and interact with him using an Internet portal.

2.5 Data storage

Data storing capabilities have been included in the on-body electronics, buffering the acquired signals in order to allow window-based signal processing. In addition, the storage allows burst transition in between the on-body electronics and the mobile 'phone, resolving the problems caused by short periods of inavailability of the transmission channel. In MyHeart systems, the buffering is performed at the concentrating node (on-body electronics) and on the mobile 'phone.

3 On body ECG processing

Electrocardiogram (ECG) is one of the most relevant biological signals: the heart beat rate (HR) is easily extracted from the ECG and the continuous evolution of the ECG waveform is used to diagnose several cardiac disorders. In the first phase of the MyHeart project, two ECG processing algorithms have been implemented in the on-body processing platform.

3.1 Heart Rate estimation

The most commonly used method of heartbeat rate measurement is to detect the R-wave peaks from the QRS complex: the intervals between two consecutive R-waves are then interpreted as indications of heart beat peridiocity. Among the several proposed approaches in the state-of-the-art [8, 4, 1, 13, 12, 4, 1] we suggest detection of the R-wave peaks with a zero-crossing of the first derivative of the signal, when the raw signal and its second derivative are above a certain threshold (figure 3).

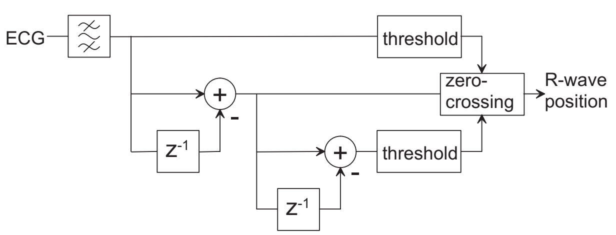

Figure 3. Block diagram of the HR estimation

The first and second derivative can be easily estimated using digital signal processing and the thresholds are continuously adapted according the the energy of the raw ECG. A discrimination strategy is also applied to the RR intervals in order to eliminate unlikely false beat periods due to signal artifacts, where intervals differing from their neighbors are discarded. Because of its very low computational cost, such an approach can be embedded in low-complexity platforms.

3.2 QRS complex enhancement

A simple mechanism of enhancing the continuous ECG waveform has also been embedded in the on-body electronics [2]. Because of the variable skin-electrode interfaces (especially due to motion artifacts), the QRS complex is continuously degraded and becomes difficult to interpret. With our enhancement procedure, we provide medical doctors with an averaged QRS complex containing the information from some successive cardiac events: Figure 4 summarizes this QRS averaging approach. As depicted, a reliability index is used to control the QRS updating dynamics.

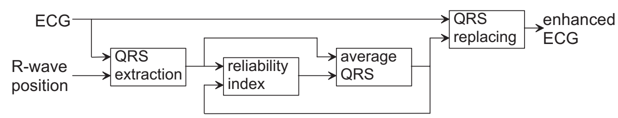

Figure 4. ECG enhancement block diagram

An example of degraded and enhanced ECG is showed in Figure 5. This restoration approach is optimal in the sense that additive noise is succesfully reduced, however it can only be applied to clinical diagnosis when short time variations between consecutive QRS complexes are irrelevant.

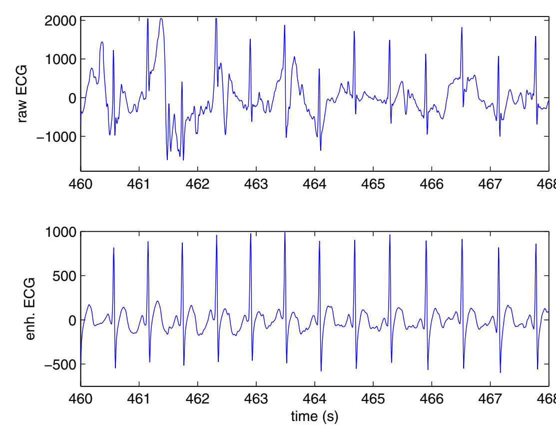

Figure 5. A real example of ECG enhancement. Above: raw ECG signal recorded with a MyHeart textile. Below: the enhanced ECG

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4 On body Activity Classification

Knowledge of the activity being performed by the monitored subject is crucial for the correct interpretation of ECG variability: while a sudden increasing heart rate should generate a tachycardia alarm during resting periods, it should not be specially handled during sport activities. An automatic activity classification algorithm is therefore mandatory for the segmentation of cardiac data and for supporting alarm generation.

In the MyHeart project, a low-complexity algorithm for ambulatory activity classification has been successfully implemented [14]. Based on the data obtained by a single-axis accelerometer embedded in the on-body electronics, the algorithm provides a continuous classification of the activity and estimates an index of activity intensity. The activity classes being currently recognized are: resting, lying, walking, running and going up/downstairs. The classification is based on the detection of basic motion patterns and the mapping to a kinematic model of human motion: some examples of basic human motion patterns are displayed in Figure 6. The validation of the algorithm has been done over 100 minutes of real activity data, and an overall score of 87% has been achieved.

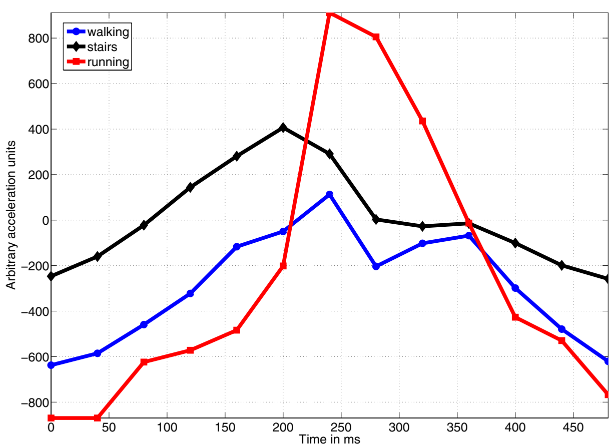

Figure 6. Some basic acceleration patterns of human motion: walking, running and going upstairs

5 Conclusions

The medical and technical potential of smart clothes in the field of 24h monitoring has been presented in this work. After defining the specifications required by a network of several distributed body-sensors, two medical applications to such architecture have been exposed: the processing of the textile-ECG and the classification of continuous motion activity. All the data presented in this paper have been obtained from real smart clothes in the context of the European IST project MyHeart. In the following months, the presented architecture and signal processing applications will be clinically validated.

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